Surface Brightness Fluctuations: A Case for Extremely Large Telescopes

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Abstract. The Surface Brightness Fluctuations (SBF) Method for distance determinations of elliptical galaxies is been modeled in order to investigate the effect of the Point Spread Function (PSF). We developed a method to simulate observations of SBF of galaxies having various properties and located at different distances. We will use this method in order to test the accuracy on the estimates of the extra-galactic distances for PSFs representing typical seeing conditions, AO systems and for future observations with ELTs close to the diffraction limit.

1 The SBF Method

The SBF Method (Tonry & Schneider 1988) measures the irreducible mottling in an early-type galaxy image due to the Poisson fluctuations in the finite number of stars per pixel. The method has important applications for both extra-galactic distance (e.g. Jensen et al. 1998) and stellar population (e.g. Blakeslee et al. 2001) studies. Its advantage is based on the fact that if we observe the same region of two identical elliptical galaxies at different distances, the one being twice as far away as the other, the more distant galaxy would have four times more stars contributing the same average flux into the pixel as the stars of the closer. The pixel-to-pixel variation in the flux due to fluctuations in the number of stars then scales inversely to the distance and so the fluctuations in surface brightness can be used as a distance indicator.

2 Simulations of Observations on Elliptical Galaxies

We simulate surface brightness profiles and the SBF of elliptical galaxies *at distances of our choice*. We then convolve them with various kinds of PSF in order to simulate their observations. The PSF is considered for three cases: *(α)* seeing-limited observations, *(β)* observations with nowadays available *Adaptive Optics* (AO) systems, and *(γ)* with *Multi-Conjugate Adaptive Optics* (MCAO) systems, which are to be used for ELTs. Thus, the first part of our method consists of three steps (see Fig. 1):

1. Modeling of the Surface Brightness Profiles of typical elliptical galaxies.
   The simulated surface brightness profiles are assumed to follow Sersic ($r^{1/n}$) law. A profile for $n = 4$ (de Vaucouleurs law) is given as:

$$\mu(r) = \mu_{\mathrm{e}} + 8.3268 \left[\left(\frac{r}{r_{\mathrm{e}}} \right)^{1/4} - 1 \right] \text{and } \mu_{\mathrm{e}} = 5 \log(r_{\mathrm{e}}) + m + zp + c \quad (1)$$

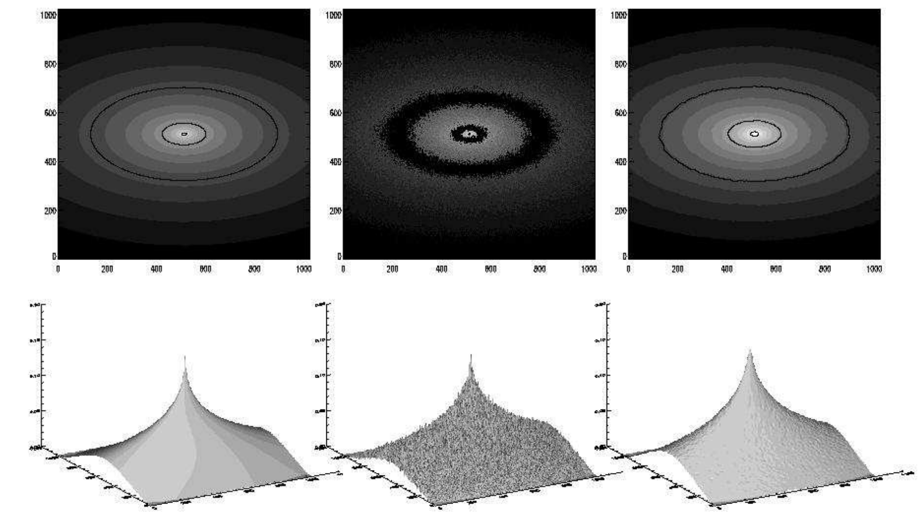

Fig. 1. Grayscale contours (top panel) and 3D brightness distributions (bottom panel) of a simulated galaxy. The example shows an E5 galaxy with $R_{\mathrm{eff}} \simeq 7.5$ kpc located at 20 Mpc following a de Vaucouleurs profile. The three steps of the simulations are shown: The model of galaxy's brightness profile (*right*), its SBF (*middle*) and the image convolved with a Gaussian PSF of FWHM = 5 px (*left*). A 1024 × 1024 pixel CCD array with a pixel scale of $0\farcs146$ was assumed.

where μ_{e} is the surface brightness of the galaxy at its effective radius r_{e}, while m is its apparent magnitude. Among the input parameters for this step is the distance of the galaxy, so we decide in advance how far away the galaxy is located. We are also able to define the wave-band at which the galaxy is being observed.

2. Modeling the surface brightness fluctuations of the galaxies.
   The reproduction of the SBF of the simulated galaxies is done by the introduction of Poisson noise to the surface stellar density of every pixel of the model image assuming a luminosity function for the stellar population of each galaxy.
3. Convolution with the PSF.
   This is the final step for the construction of simulated observations of elliptical galaxies on arrays with size and resolution of our choice.

3 Measurements of the SBF of the Simulated Galaxies

The second part of our method includes the measurements of the SBF of the simulated galaxies, the computation of their SBF magnitude and in consequence the estimation of the distance of the galaxies. In order to measure the SBF of an observed galaxy the power spectrum of the reduced image must be computed. It

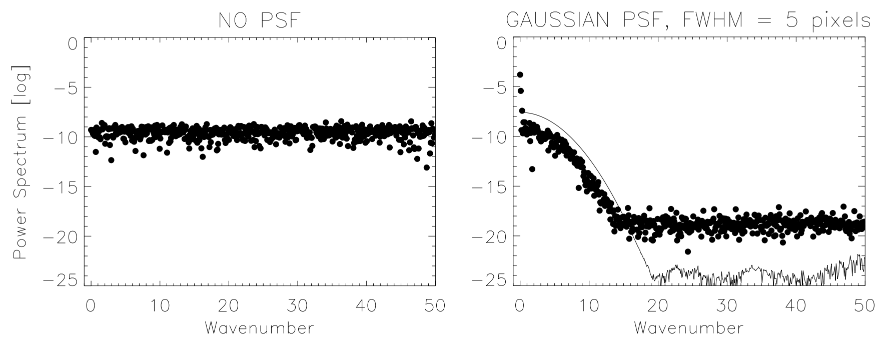

Fig. 2. Power spectrum of a simulated E5 galaxy with $R_{\mathrm{eff}} = 10$ kpc, located at 35 Mpc. *Left*: The power spectrum of the image when there is no PSF effect (*Left*) and for seeing $0\farcs73$ (*Right*). In the later the line shows the power spectrum of the PSF.

is given as the linear combination of the fluctuation power P_0 times the power spectrum of the PSF E_{psf} and a white noise component, P_{w}:

$$P(k) = P_0 E_{\mathrm{psf}} + P_{\mathrm{w}} \tag{2}$$

In consequence *the power spectrum of the PSF defines the one of the image of the galaxy itself.* This is demonstrated in Fig. 2, where we show the power spectrum of simulated observations on an elliptical galaxy without any PSF at all (left) and with seeing limited conditions (right).

4 Conclusion

We present a model of the SBF method for distance estimations. Our aim is to use it for the investigation of hypothetical SBF observations with ELTs. Specifically, the measurements of the SBF amplitude of simulated observations of elliptical galaxies with various properties can lead to estimations of the distances of the galaxies with the use of available SBF calibrations (e.g. Tonry et al. 2001). The comparison between the input distance that was initialy selected for every galaxy and the estimated value will allow us to define the accuracy of the SBF method with the use of various telescopes and under various observational conditions. Thus we will be able to study the accuracy and the limitations of SBF observations with future ELTs.

References

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